Reproducibility of the lung anatomy using Active Breathing Control

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Reproducibility of the lung anatomy using Active Breathing Control: Dosimetric consequences for scanned proton treatments.

Lydia A. den Otter[1], Roel G.J. Kierkels[1], Allia Kaza[2], Arturs Meijers[1], Martin O. Leach[2], David J. Collins[2], Johannes A. Langendijk[1], Antje C. Knopf[1]

1: Department of Radiation Oncology, University Medical Center Groningen, University of Groningen, The Netherlands

2: CR-UK Cancer Imaging Centre, The Institute of Cancer Research and The Royal Marsden Hospital, London, UK.

ICR The Institute of Cancer Research

INTRODUCTION

The treatment of moving targets with pencil beam scanning (PBS) is challenging. PBS is a high precision treatment technique, making it sensitive to tumour motion. In order to mitigate motion, irradiation during breath-holding can be applied. However, the treatment delivery often exceeds feasible breath-hold durations. Therefore, high breath-hold reproducibility is required in order to deliver precisely, also after performing multiple breath-holds. A device that is used in our hospital, Active Breathing Coordinator (ABC), assists with breath-holding by controlling the lung volumes. At the Institute of Cancer Research (ICR), the reproducibility of ABC was investigated for five volunteers using repeated MR imaging. For this research the data was shared and a method was developed to investigate the dosimetric consequences of using ABC for scanning proton therapy, applied in 3 exemplary non-small-cell lung cancer patients.

PURPOSE

To investigate the dosimetric consequences of anatomical reproducibility uncertainties in the lung under ABC to evaluate the robustness of scanned proton treatments.

MATERIALS & METHODS

- The data acquired and shared, included T1-weighted MRIs for five volunteers that were acquired during ABC. For each volunteer 4 subsequent breath-holds were performed and MR images were acquired **(figure 1)**.
- Between the first and subsequent MRIs deformable image registration was performed, resulting in deformation vectors fields (DVFs) showing the displacements between the different breath-holds.

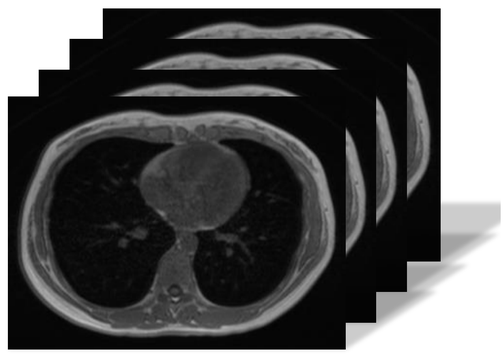


Figure 1: Per volunteer 4 subsequent MRIs were acquired during ABC.

- The DVFs were used to deform 95% inspiration phase CTs of 3 randomly selected non-small-cell lung cancer (NSCLC) patients , matched to one of the volunteers (**figure 2**). Per patient, an intensity-modulated proton treatment (IMPT) plan was created. The IMPT plans were then recalculated for the deformed CTs and dosimetric results were compared.

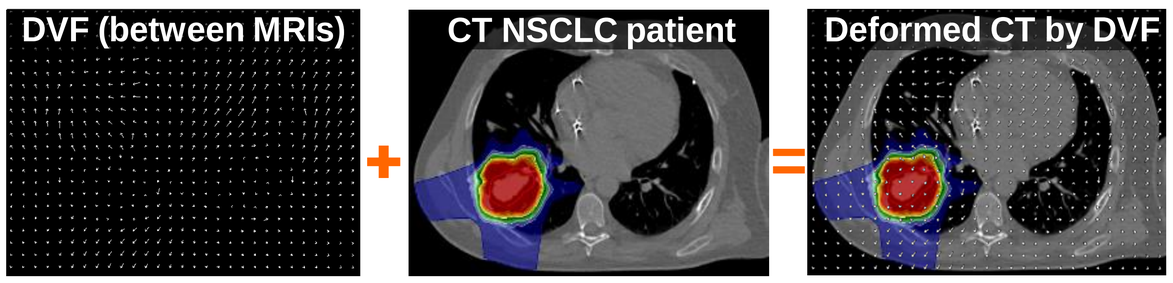


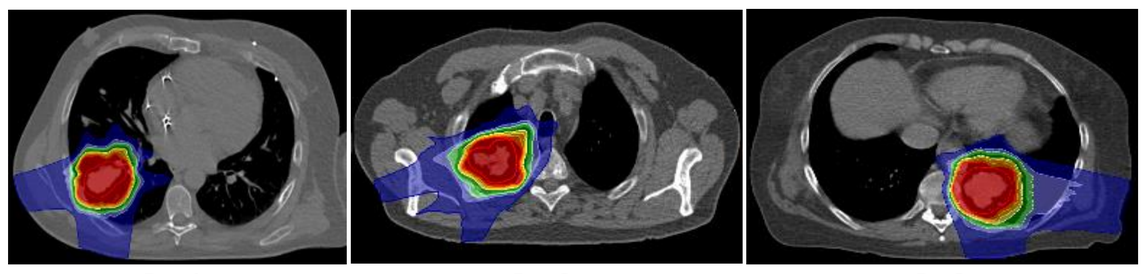
Figure 2: Application of the motion fields onto the CT scans of NSCLC patients, resulting in deformed CTs, after which the doses were recalculated.

RESULTS

The following results were observed:

- Dosimetric consequences were negligible for patient 1 and 2 (**figure 3**).
- Patient 3 showed a decreased volume (95.21%) receiving 95% of the prescribed dose for one deformed CT.
- The volume receiving 105% of the prescribed dose increased from 0.0% to 9.9% for patient 3.
- The heart volume receiving 5 Gy varied by 2.3% for patient 3.

Figure 4 shows the dose volume histograms for all relevant structures for patient 3.



	CTV $V_{95\%}$ (%)			CTV $V_{105\%}$ (%)			Heart V_{5Gy} (%)		
	Pt. 1	Pt. 2	Pt. 3	Pt. 1	Pt. 2	Pt. 3	Pt. 1	Pt. 2	Pt. 3
Planning CT	100.00	99.99	100.00	1.20	0.00	0.00	0.00	6.56	13.19
Deformed CT 2	99.99	99.96	99.83	6.73	1.06	4.12	0.00	6.65	11.67
Deformed CT 3	99.99	99.94	99.84	8.73	2.23	4.16	0.00	6.21	11.68
Deformed CT 4	100.00	99.97	95.21	9.60	1.36	9.87	0.00	6.64	10.92

Figure 3: Transverse slices showing the various tumour locations (for patient 2 and 3 also lymph nodes were included) with dose distributions, beam paths, and irradiated lymph nodes in case of patients 2 and 3. In addition, target coverage parameters and the volume of the heart receiving 5 Gy are evaluated for the deformed CTs.

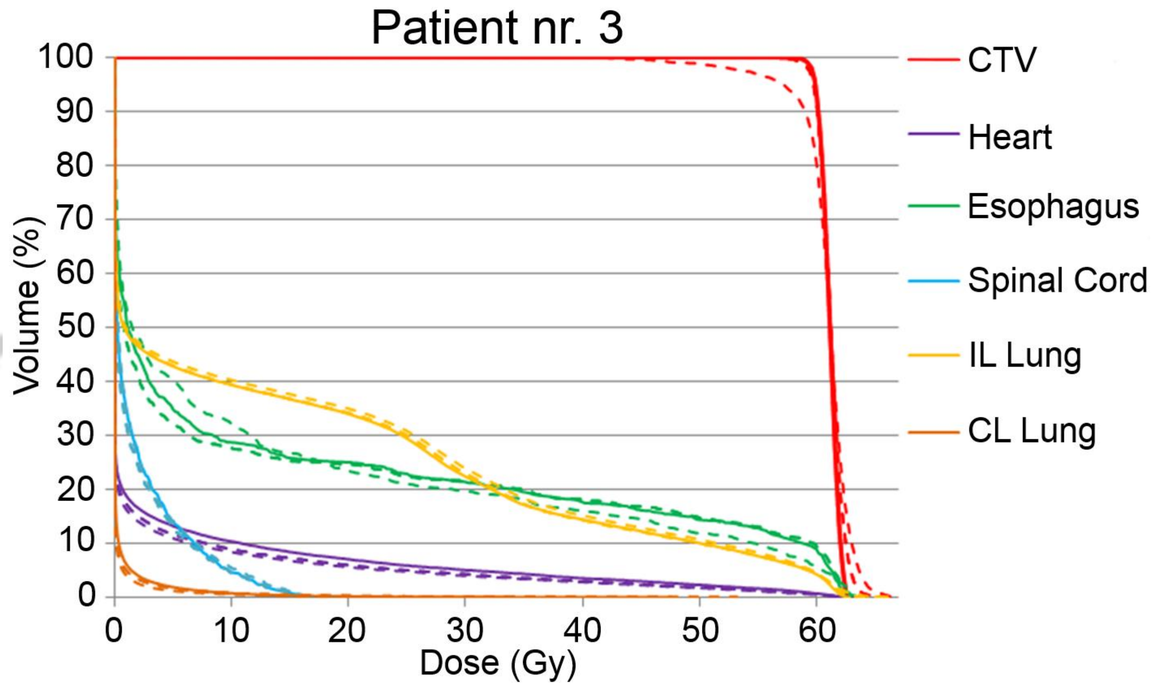


Figure 4: Dose volume histograms of the CTV and organs at risk of patient 3. The solid lines represent the original planning CT doses and the dotted lines the doses after repeated breath-holds.

DISCUSSION

With this unique dataset of repeated MRIs under ABC a close look could be taken at the reproducibility and possible use of ABC breath-hold for pencil beam scanning. The influence seems to be limited to a small decrease in target coverage and an increase up to 9% of high dose regions. Though one specific case shows that it is still a possibility to lose target coverage with increasing number of breath-holds and large differences between the breath-holds. Future research will include true breath-hold CT scans and more patients.

CONCLUSION

Based on the studied patients, our findings suggest the following:

- Variations in breath-hold have limited effect on the dose distribution for most lung patients.
- However, for some patients a decrease in target coverage can occur as result of differences in repeated breath-holds during ABC.

Further investigation of dosimetric consequences from intra-fractional breath-hold uncertainties in the lung under ABC are currently performed at the UMCG.

References: Kaza, E., Dunlop, A., Panek, R., Collins, D. J., Orton, M., Symonds-Tayler, R., McQuaid, D., Scurr, E., Hansen, V. and Leach, M. O. (2017), Lung volume reproducibility under ABC control and self-sustained breath-holding. J Appl Clin Med Phys, 18: 154–162. doi:10.1002/acm2.12034

l.a.den.otter@umcg.nl